Shallow Convective Snow from a GPM Microwave Imager Perspective: Snowfall Quantitative Precipitation Estimation Strengths and Weaknesses

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Introduction

Shallow convective snow related to cold air outbreaks interacting with large bodies of unfrozen water influences regional hydrology and is often associated with extreme snowfall accumulation events. This work focuses on the ability of the Global Precipitation Measurement (GPM) passive microwave sensors to detect and provide quantitative precipitation estimates for intense convective lake-effect snowfall events over the United States Lower Great Lakes region.

The two main scientific questions we want to address with this work are:

- Is GPM's Microwave Imager (GMI) able to detect intense shallow convective snowfall events?
- If yes, is the GMI Goddard PROfiling (GPROF) algorithm able to translate the TB's signal into physically meaningful snowfall rate estimates?

Case Studies

We present here two intense, multi-day lake-effect snow events, on November 19-21 2014 and January 8-10 2015 over the Lower Great Lakes Region. GPM overpasses the region of interest on November 20 2014 at 18.20 UTC (orbit #4140) and on January 09 2015 at 12.26 UTC (orbit #4914).

TB's signatures:

In both cases high frequencies (89 to 183 GHz) Brightness Temperature (TB) signatures show a clear signals (e.g., TB depressions due to ice scattering in intense snow bands and/or TB increases due to cloud liquid water emission at 89 GHz) for the snow bands over Lakes Erie and Ontario (Figs. 1 and 2).

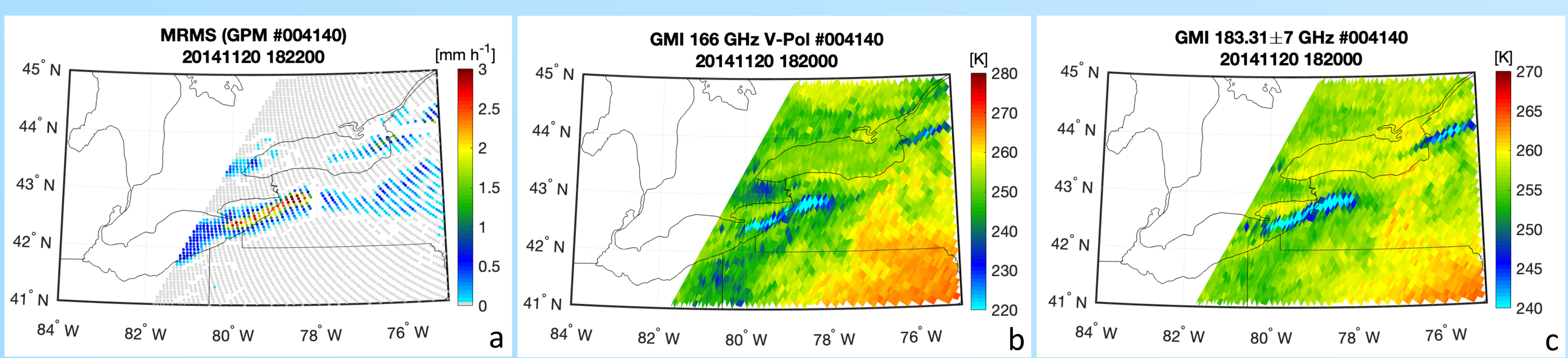

Figure 1: a) MRMS precipitation product and GMI b) 166 GHz V-pol and c) 183 ± 7 GHz TBs over Lakes Erie and Ontario on 20 November 2014 at 1820 UTC (orbit #4140).

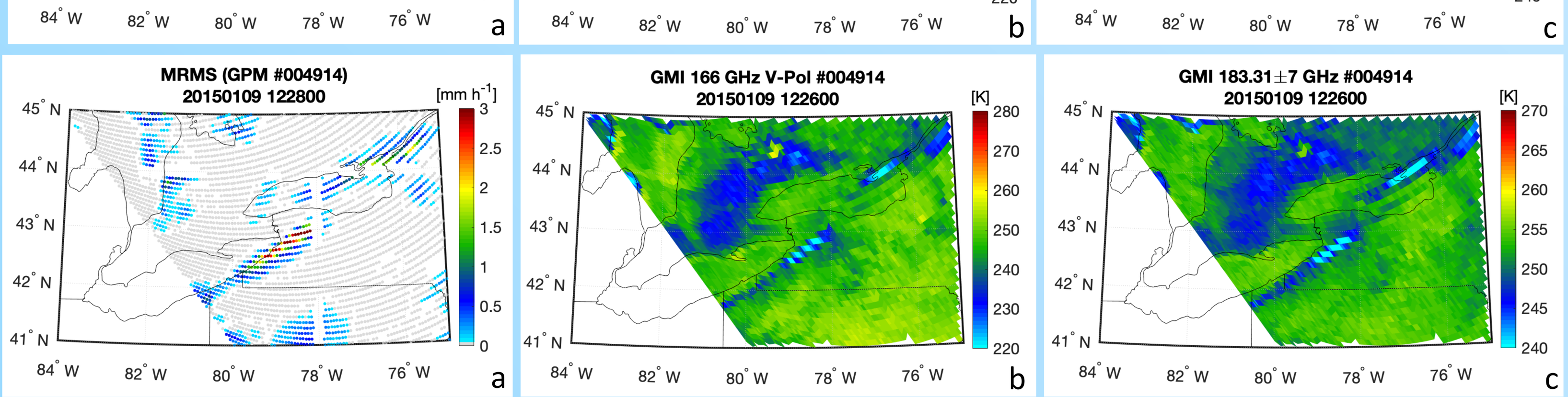

Figure 2: a) MRMS precipitation product and GMI b) 166 GHz V-pol and c) 183 ± 7 GHz TBs over Lakes Erie and Ontario on 09 January 2015 at 12.26 UTC (orbit #4914).

Operational GPROF (V05)

Comparing operational GPROF (precipitation threshold 0 mm h^{-1}) to MRMS precipitation product (precipitation threshold 0.1 mm h^{-1}):

- Many false alarm pixels over land (Table 1 'FAR oper.')
- The 'non random hit' rate (Heidke Skill Score) is low in both cases (Table 1 'HSS oper.').
- Correlation is higher for orbit #4140 (R=0.65) and lower for orbit #4914 (R=0.43).

'Precipitation Rate Threshold' (PRT) GPROF (V05)

Since GPROF indicates light precipitation over non precipitating areas according to MRMS, we filtered out false precipitating pixels applying a Precipitation Rate Threshold (PRT). PRT has been chosen case-by-case with a HSS systematic analysis (PRT=0.08 mm h^{-1} orbit #4140, PRT=0.11 mm h^{-1} orbit #4914)

- FAR and HSS are both improved (Table 1 'FAR PRT' and 'HSS PRT').
- Correlation is improved for orbit #4914 and slightly worse for orbit #4140 (Table 1 'R PRT').

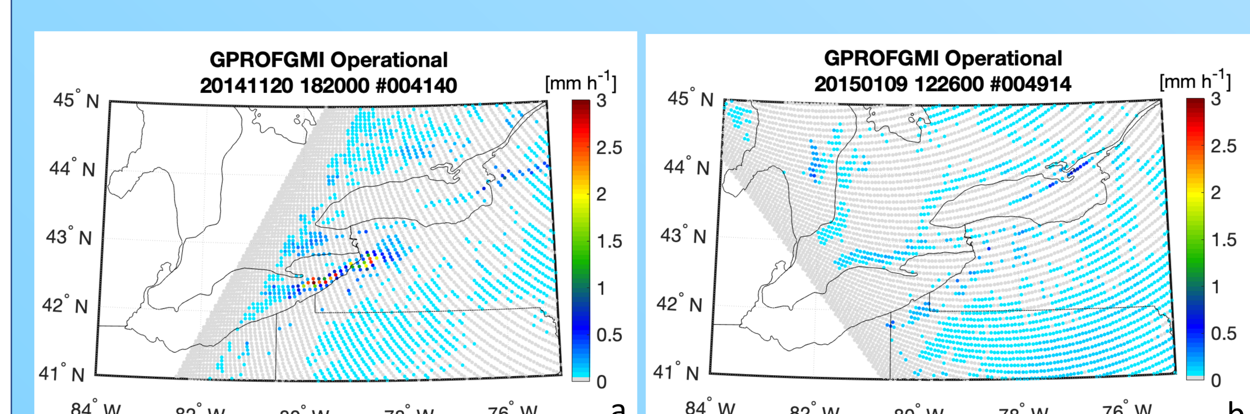

Figure 3: Operational GPROF precipitation rate (using SurfPrecip parameter) with 0 mm h^{-1} precipiation threshold for a) orbit #4140 and b) orbit #4914.

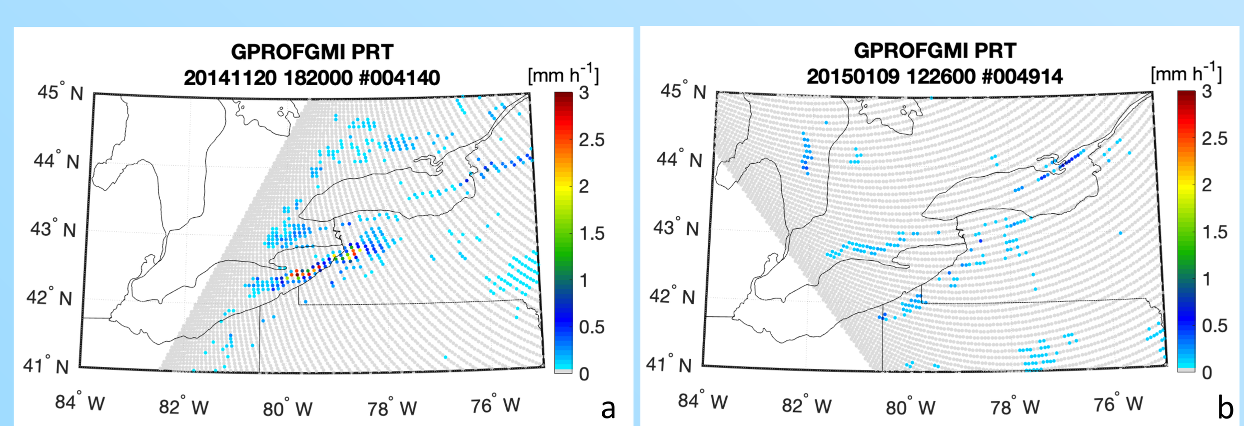

Figure 4: PRT GPROF precipitation rate (using SurfPrecip parameter) for a) orbit #4140 with 0.08 mm h^{-1} precipitation threshold and b) orbit #4914 with 0.11 mm h^{-1} precipitation threshold.

Results

- *A-priori database representativeness*

Considering 'coastline' and 'snow covered' surfaces, the number of profiles within the TPW<5 mm and T2m<273 K sub-sets (bins in the bottom left corner of the plots, red lines plotted as reference – Fig.5), is low, with just 1.3% of all precipitating elements for 'coastline' (Fig.5a) and 7.2% of 'Maximum snow cover' sub-set (Fig.5b).

The Probability Density Functions (PDFs) of each *a-priori* database sub-set illustrate the low probability of higher precipitation rate events within the database. Only 120 (126) elements with rates over 1 mm h^{-1} are found in the 'coastline' ('maximum snow cover') for T2m<273K and TPW<5mm (black and light blue solid lines in Fig.6) corresponding to the only 0.03% (0.3%) of all precipitating elements in the *a-priori* low T2m and low TPW subsets.

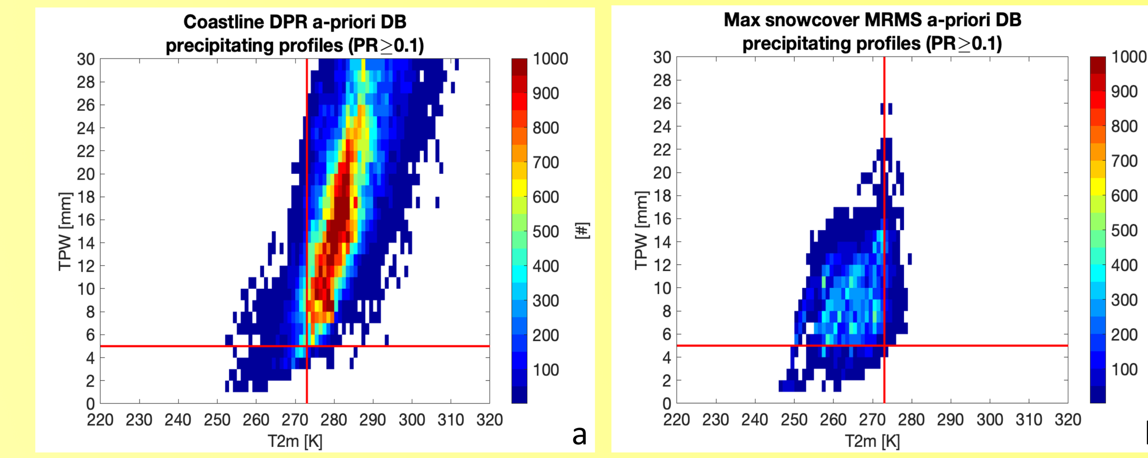

Figure 5: 2D distributions of GPROF a-priori database elements (surface precipitation elements with PR ≥ 0.1 mm h^{-1}) (red lines for T2m=273K and TPW=5mm are plotted as reference). GPM (GMI and DPR) data from September 2014 to August 2015 are used to construct the coastal GPROF a-priori database and GMI and MRMS data from April 2014 to August 2016 are used to construct the snow cover GPROF a-priori database. a) DPR a-priori database is used for 'coastline' b) MRMS a-priori database is used for 'maximum snow cover'.

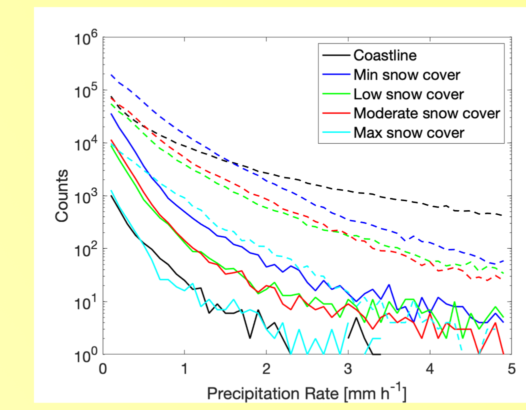

Figure 6: PDFs of precipitation rates associated with precipitating elements in the a-priori databases. Dashed lines represent the distribution of all precipitating events (PR≥0.1 mm h^{-1}), solid lines precipitating events with T2m<273K and TPW<5mm. Colors represent the different surface types.

- *Surface classification*

Since snow covered surfaces are classified by a monthly surface emissivity 'climatology' or the daily Autosnow NOAA product, the surface classification, mainly for 'coastline' could sometimes be misclassified. We forced GPROF to consider all surfaces as snow covered and therefore only the MRMS *a-priori* database has been used for test purposes. In Fig.7, the resulting maps show both detection and quantification improvements (Table 1 'forced surf.' columns).

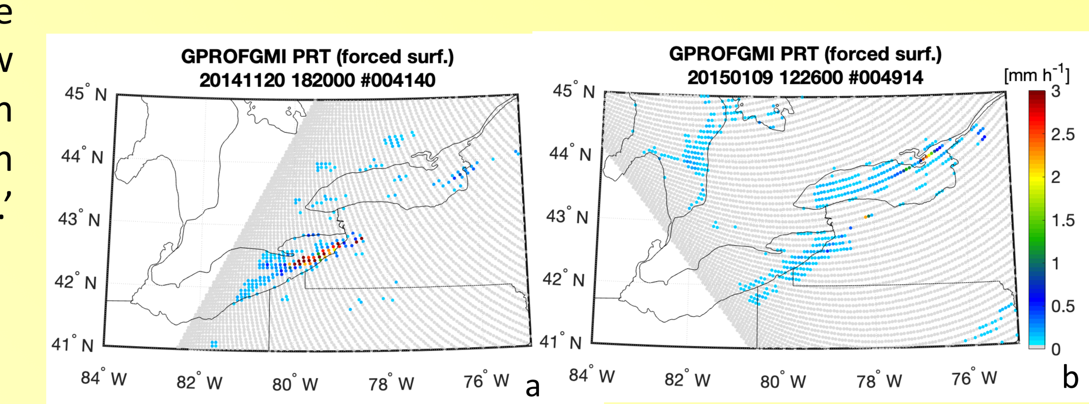

Figure 7: GPROF retrievals using only the MRMS a-priori database for a) orbit #4140 with 0.13 mm h^{-1} precipitation threshold and b) orbit #4914 with 0.1 mm h^{-1} precipitation threshold.

- *High frequency channel weighting*

The retrieval's high frequency channel weighting is based on pre-launch calculations and some tests demonstrated that changing the sensitivity improves the snowfall retrieval and detection performance (maps are shown in Fig.8 and statistical scores in Table 1 'ch sens.' columns).

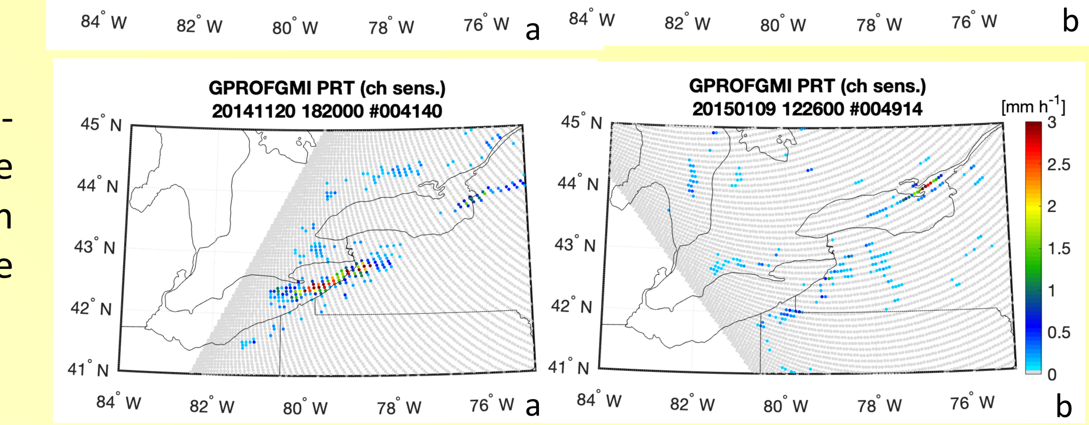

Figure 8: GPROF retrieval with a different combination of channel weighting for a) orbit #4140 with 0.14 mm h^{-1} precipitation threshold and b) orbit #4914 with 0.12 mm h^{-1} precipitation threshold.

Orbit	HSS oper.	HSS PRT	HSS forced surf.	HSS ch sens.	FAR oper.	FAR PRT	FAR forced surf.	FAR ch sens.	R oper.	R PRT	R forced surf.	R ch sens.
20/11/14 #4140	0.09	0.26	0.35	0.35	0.77	0.57	0.30	0.24	0.65	0.61	0.67	0.66
09/01/15 #4914	-0.01	0.11	0.29	0.26	0.80	0.54	0.43	0.33	0.43	0.51	0.22	0.21

Table 1: Statistical parameters for the MRMS-GPROF comparison. The different columns refer to the different GPROF analysis configurations: operational GPROF with precipitation threshold 0 mm h^{-1} ('oper.'), GPROF with a precipitation threshold based on HSS analysis ('PRT'), GPROF forced to use only the MRMS a-priori database ('forced surf.') and GPROF with a different channel weighting combination ('ch sens.').

Conclusions

- Lake-effect snow signature is clearly detected by GMI high frequency TBs.
- The operational GPROF (V05) retrievals show detection issues (high FAR and low HSS) and underestimate precipitation rates.
- For the current state of the product, users should consider a precipitation threshold (PRT), computed case-by-case using the best HSS performances that lowers the FAR, increases HSS and improves the correlation.
- The a-priori database is likely underrepresented for this particular type of event. Better populating the low TPW and low T2m sub-sets could potentially help retrievals.
- A probable misclassification of surface type (mainly 'coastline' and 'snow covered' surfaces) may be affecting the algorithm performance.
- Improving the high frequency channel weighting can improve snowfall detection and quantification snowfall rate estimate for intense lake-effect snow events.